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Technology Base 2004 Report on the Ultrasonic Calibration Test Phantom

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1 Project Overview

We designed and built a phantom consisting of vertical wires maintained under tension to be used as an ultrasonic test, calibration, and reconstruction object for the LLNL annular array scanner known as the *KCI scanner*. We provide a description of the phantom, present some example data sets, and preliminary reconstructions.

2 Project Goals

Design and build a reconfigurable ultrasonic phantom for the KCI scanner. Use it to collect well characterized data under controlled conditions for use as "canonical data sets" in testing and evaluating new inversion algorithms.

3 Relevance to LLNL Mission

The non-destructive evaluation (NDE) of objects and media of interest to LLNL/DOE/DOD is an essential part of LLNL's mission. Many NDE situations have put demands beyond the scope of the current suite of imaging algorithms. As new algorithms and codes come on line, they must be evaluated on well characterized phantoms. The Ultrasonic Calibration Test Phantom provides such a data set.

4 FY04 Accomplishments and Results

We designed and built a phantom consisting of vertical wires maintained under tension to be used as an ultrasonic test, calibration, and reconstruction object for the LLNL annular array scanner known as the *KCI scanner*. The phantom consists of top and bottom plates into which are drilled holes through which the wires are run. The holes form a geometrical pattern which govern the horizontal distribution of the wires. The plates are affixed to top and bottom mounting brackets which are pulled apart putting the wires under tension. Given that the phantom object formed by the wire distribution does not vary much in the vertical (z-direction), we assume the measured data are from a 2.5-dimensional object. The initial conceptual phantom design is presented in Figure 1

These plates are removable permitting differing designs to be used. We currently only have one design: a logarithmic spiral with equation,

$$\mathbf{r}(\theta_n) \quad = \quad a\left(\cos(\theta_n), \sin(\theta_n)\right) e^{b\theta_n}, \tag{1}$$

where

$$\begin{array}{rcll} a & \equiv & \lambda_0 & \text{is the initial radius and,} \\ \lambda_0 & \equiv & v_0/f_0 & \text{is the insonifying wavelength,} \\ v_0 & \equiv & 1500 \text{ meters/second} & \text{is the assumed background water velocity,} \\ f_0 & \equiv & 1 \text{ MHz} & \text{is the approximate insonifying frequency,} \\ b & \equiv & 10\pi/180 & \text{is the spiral growth rate,} \\ \theta_n & \equiv & \{n\Delta\theta\}_{n=0}^{N-1} & \text{are the angular locations of the wires,} \\ \Delta\theta & \equiv & 30\pi/180 & \text{is the angular increment,} \\ N & \equiv & 31 & \text{is the number of wires.} \end{array}$$

This current configuration is shown in Figure 2(a). We have allowed for an optional acrylic hollow cylinder around the phantom as shown in Figure 2(b). Figure 2(c) shows one of the plates.

The phantom is fastened into the scanner: the top block is affixed to a rod fastened to the central bore of the scanner drive; the bottom block is fastened to the bottom of the tank. Once installed, the blocks are pulled apart to render the wires taut. Figure 3 (a) shows the phantom with 31 steel taut wires. Figure 3 (b) shows the optional acrylic cylinder in place.

Figures 4 and 5 show measured time series data and spectra for the water background and 31 steel wire cases. The data are very clean. Clear and distinct sinograms of individual wires are seen in Figure 5.

The design of the phantom allows for wire of different materials to be used. We have run scans with the following combinations:

- 31 steel wires;
- 30 steel, 1 nylon;
- 25 steel, 6 nylon;
- 25 steel, 6 nylon, with the hollow cylinder;
- 2 steel, 2 nylon resolution pair;
- 2 steel, 2 nylon resolution pair, with the hollow cylinder;
- Hollow cylinder only (no wires).

Preliminary reconstructions, using Quantitative Time-Domain Multiview Imaging (QMTDI), of the 30 steel/1 nylon and 25 steel/6 nylon combinations are shown in Figures 6 and 7.

5 Future Work

We are very pleased with the phantom design and quality of the measured data which will be used as “canonical data sets” for testing new inversion and detection algorithms. The flexibility of the phantom allows us to design new models to simulate real NDE problems of interest to LLNL, DOE, and DOD. Additionally, we will share these data sets with outside collaborators such as those at the Center for Subsurface Sensing and Imaging Systems (CenSSIS) in order to identify researchers who have NDE solutions of interest to LLNL.

We will be reconstructing the current data sets with our three current, mature algorithms:

- Time reversal (TR) [1];

- Hilbert space inverse wave (HSIW) [2, 3];
- Quantitative Time-Domain Multiview Imaging (QMTDI) (*reference currently being prepared for publication*).

References

[1] S. K. Lehman and A. J. Devaney. Transmission mode time-reversal super-resolution imaging. *The Journal of the Acoustical Society of America*, **113**(5):2742–2753, May 2003.

[2] A. J. Devaney and M. Dennison. Inverse scattering in inhomogeneous background media. *Inverse Problems*, **19**:855–870, 2003.

[3] S. K. Lehman and S. J. Norton. Radial reflection diffraction tomography. *The Journal of the Acoustical Society of America*, **116**(4), October 2004.

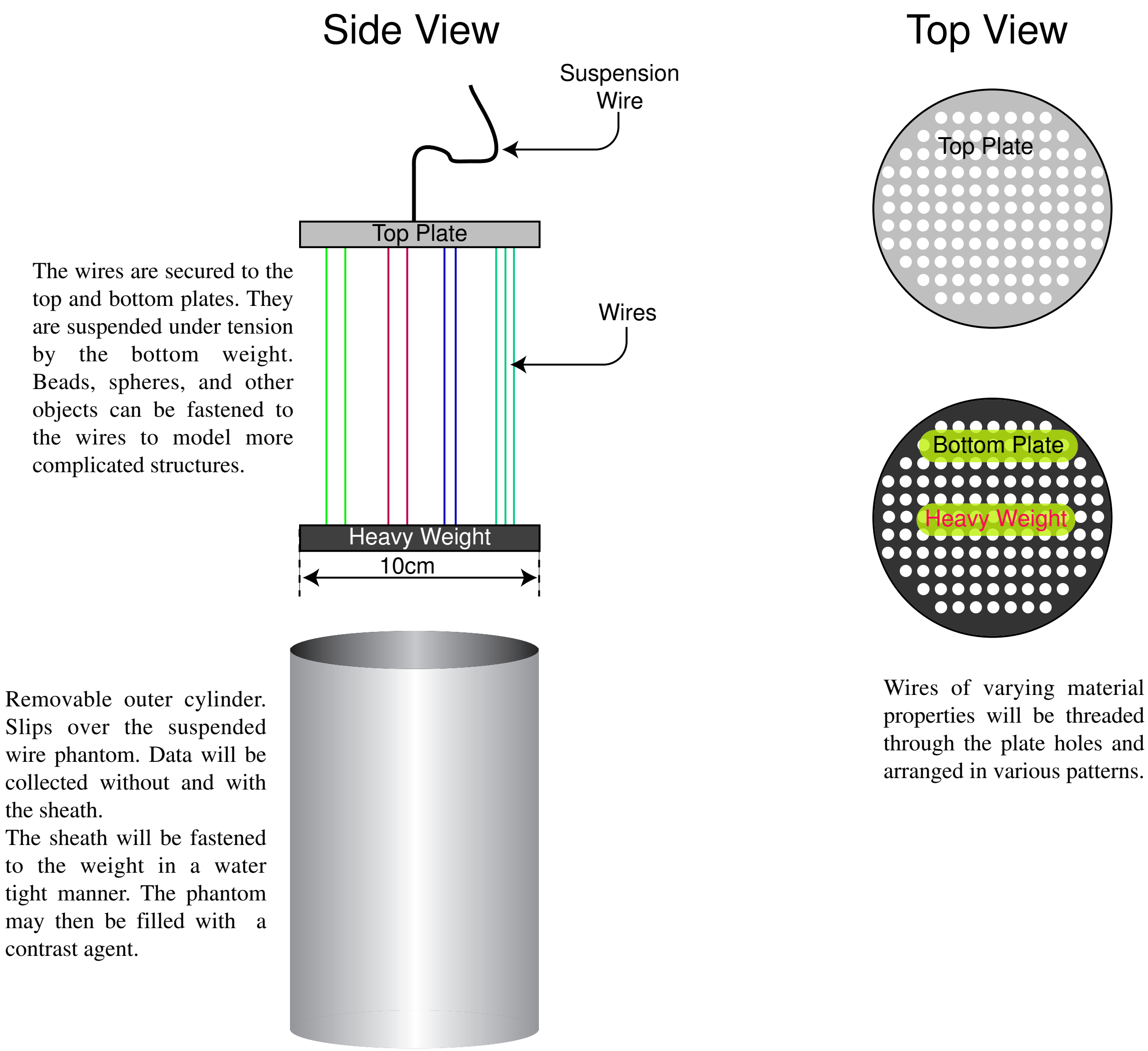
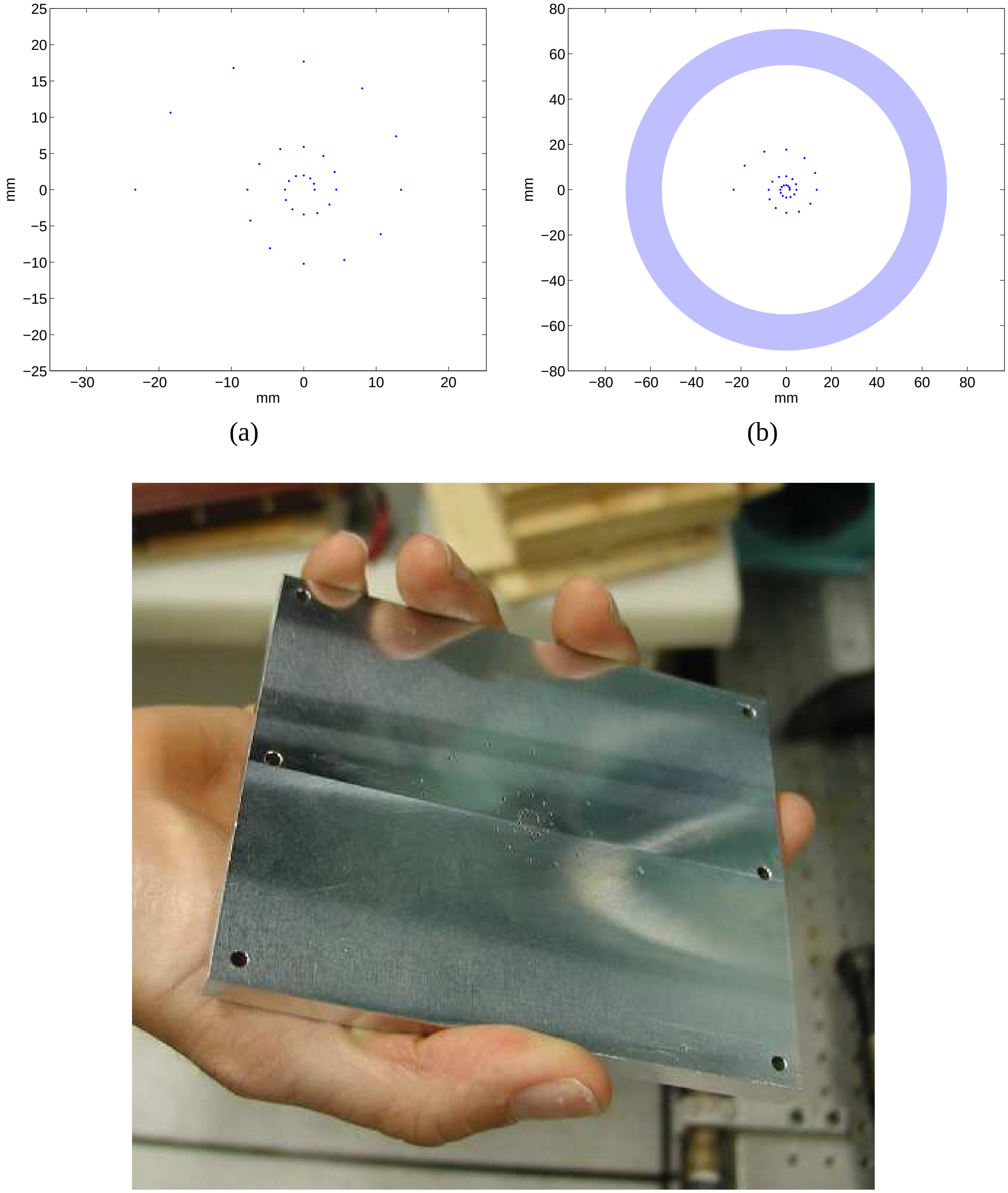


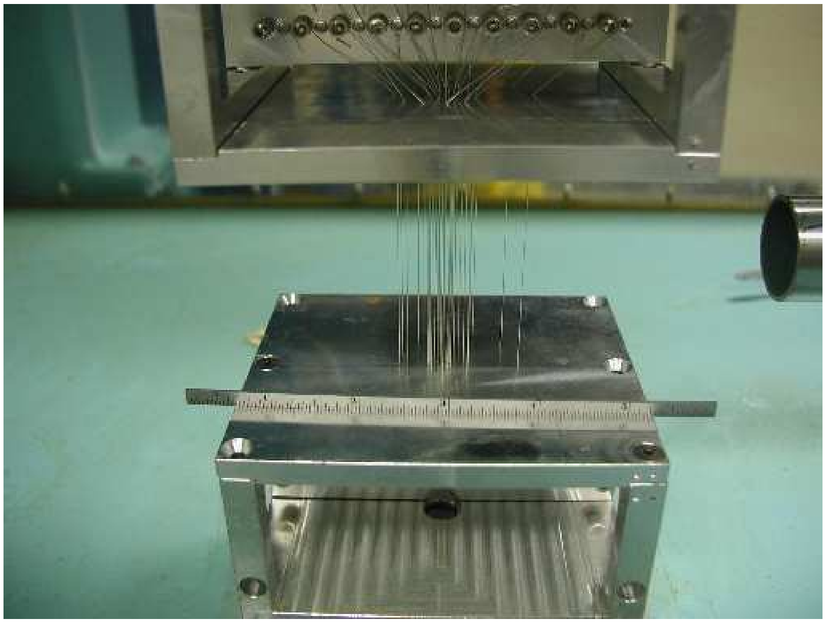
Figure 1: *Preliminary wire phantom conceptual design.*



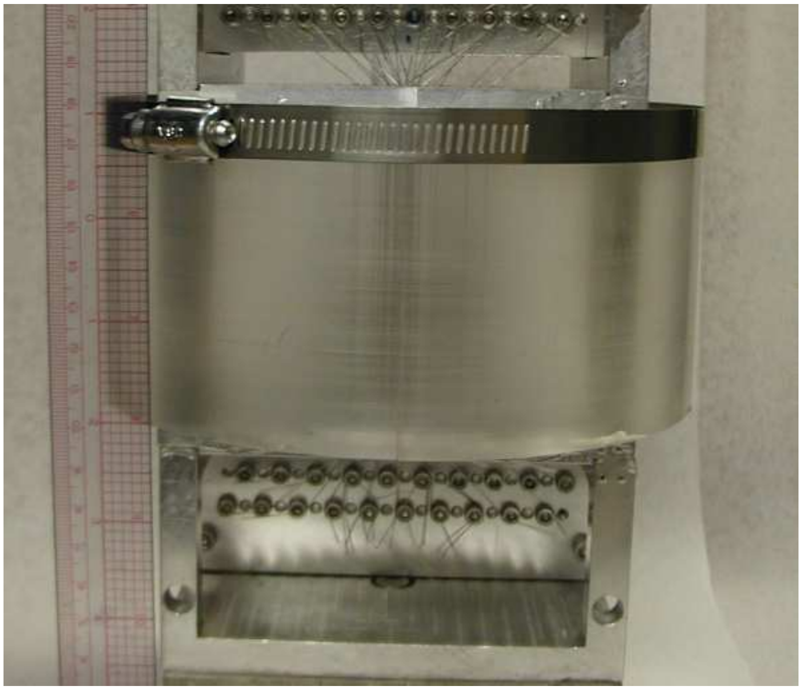
(a) (b)

(c)

Figure 2: *Basic spiral phantom design. (a) Without hollow cylinder. (b) With cylinder. (c) Photograph of wiring plate with holes.*



(a)



(b)

Figure 3: *(a) Phantom after the wires were pulled taut. (b) Phantom with optional acrylic hollow cylinder.*

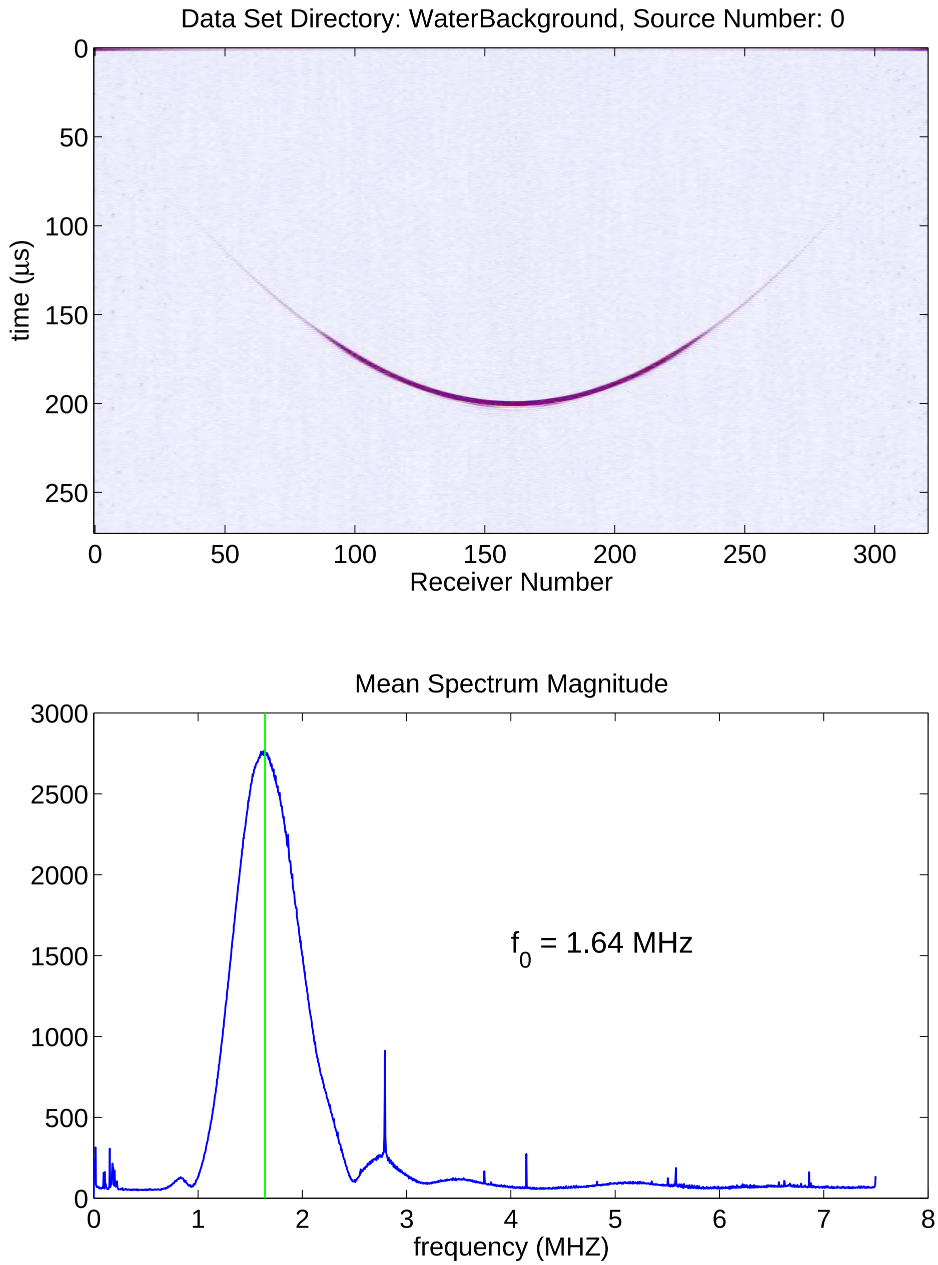


Figure 4: *Water background.*

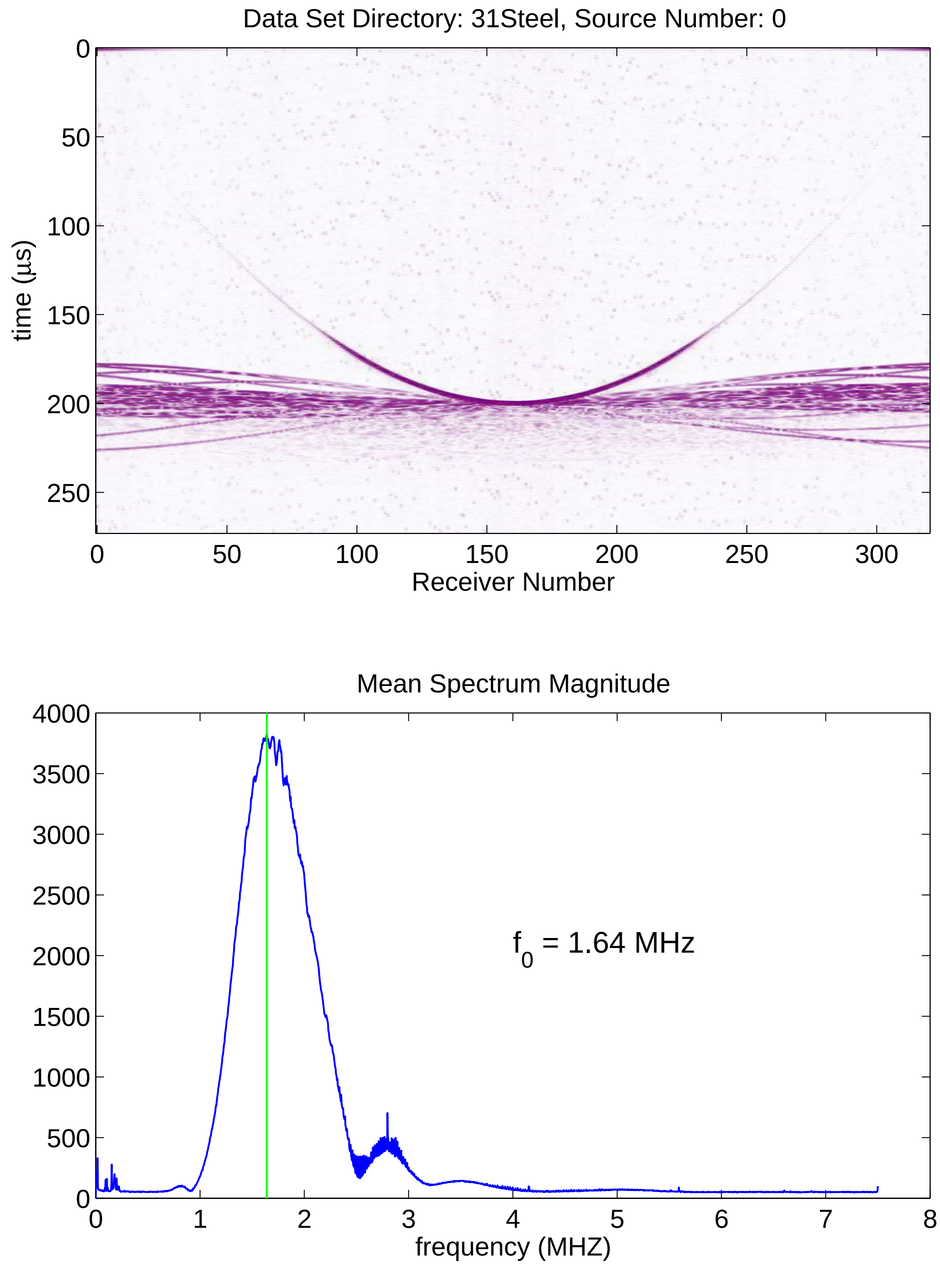


Figure 5: *31 steel wires.*

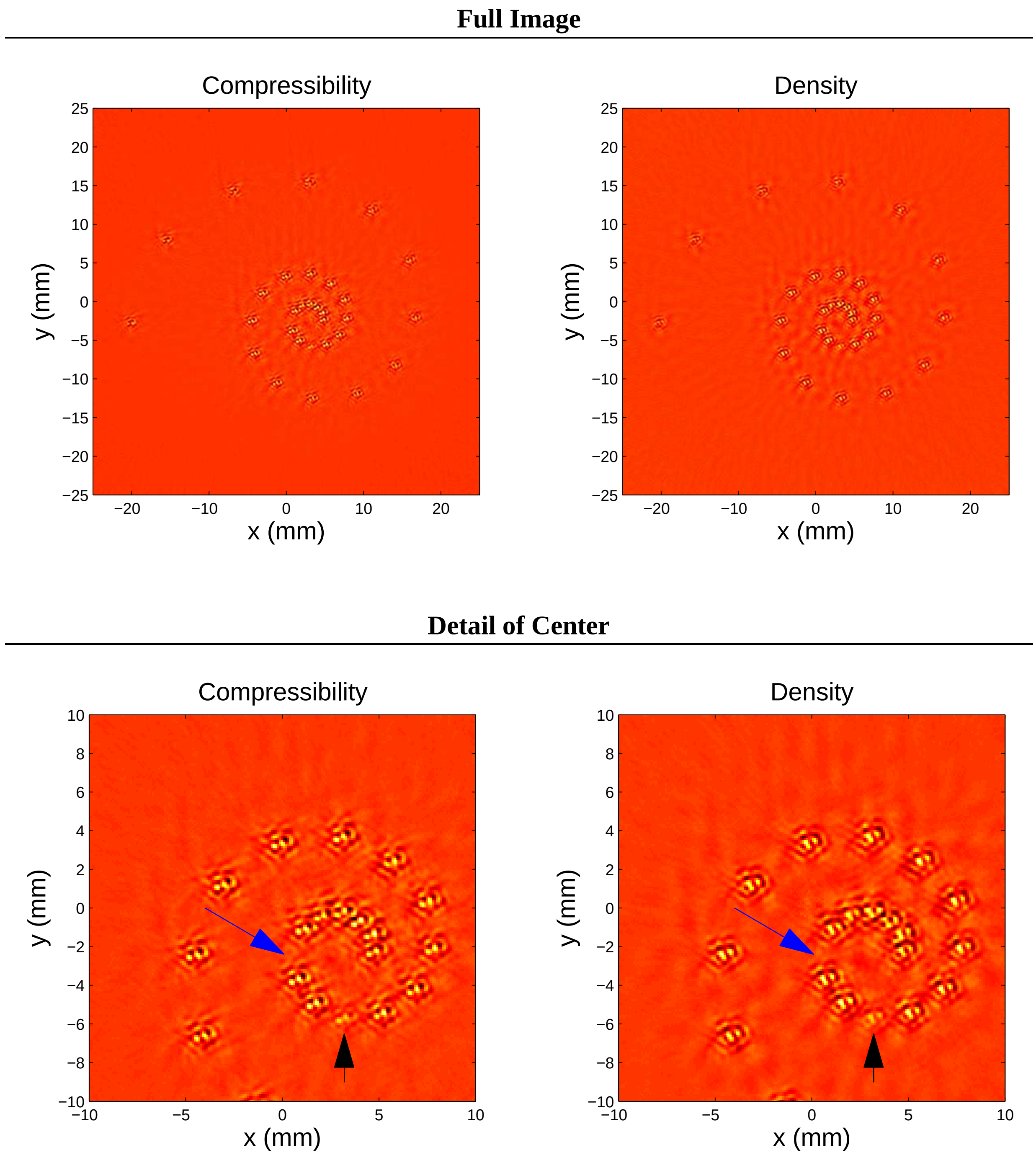


Figure 6: *Preliminary reconstructions using Quantitative Time-Domain Multiview Imaging (QMTDI) method of one nylon wire case. The nylon wire is located at the 6 o'clock position on the inner most spiral arm as indicated by the* **black** *arrow. The* **blue** *arrow indicates the location of a missing wire at the 9 o'clock position.*

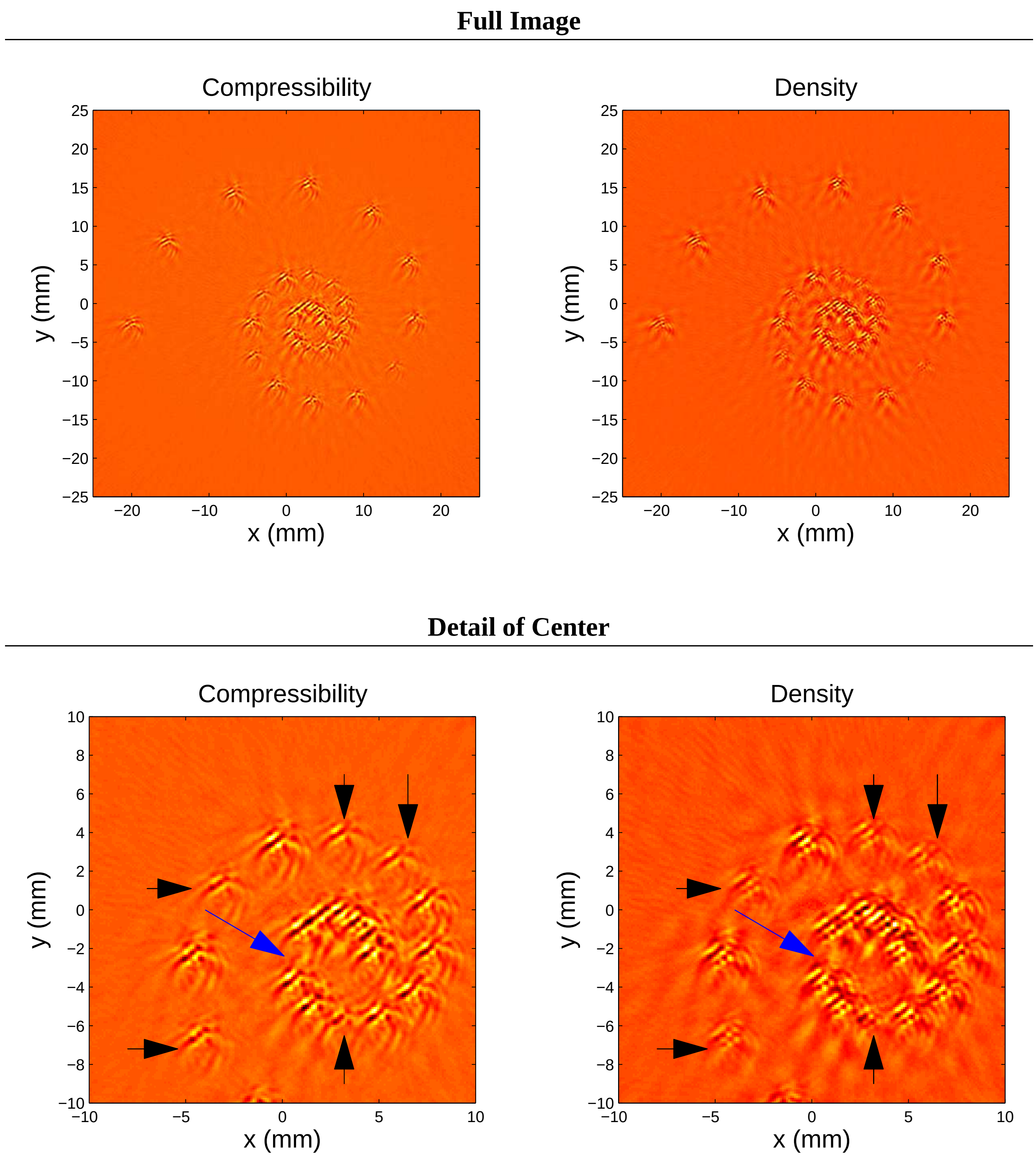


Figure 7: *Preliminary reconstructions using Quantitative Time-Domain Multiview Imaging (QMTDI) method of six nylon wire case. The* **black** *arrows indicate the locations of the nylon wires. The* **blue** *arrow indicates the location of a missing wire at the 9 o'clock position.*